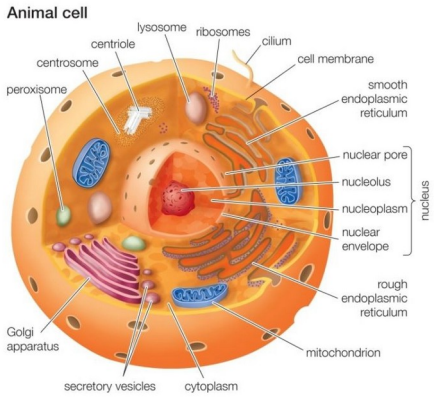
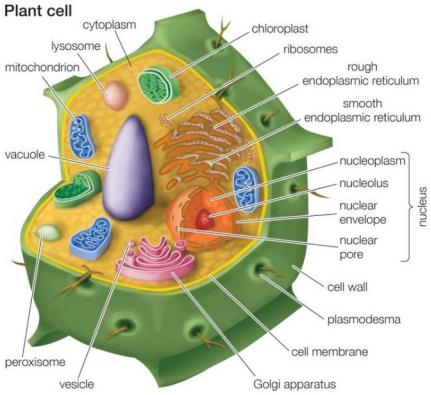
The Khyber Islamic Model School System

Akbarpura District Nowshera

A journey towards :





Cell Biology :

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MD

BPS = 12

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Preface :

The study of cells—commonly known as cell biology—forms the cornerstone of biological sciences. This textbook is designed to provide a comprehensive understanding of the structure, function, and dynamics of cells, which are the basic units of life. Whether one is studying plants, animals, or microorganisms, all life is based on the same cellular processes.

This book is intended for students and educators alike who are beginning their journey into the fascinating world of cell biology. It covers a broad range of topics, from the fundamental properties of cells and their components to more advanced concepts such as cell signaling, division, and molecular mechanisms of disease.

Each chapter is crafted to introduce key concepts in a clear and structured manner, providing both the theoretical background and practical understanding necessary for further exploration. The book incorporates a blend of classic cell biology knowledge along with cutting-edge research to keep students informed about the latest developments in the field.

To facilitate learning, this textbook also includes diagrams, illustrations, and review questions at the end of each chapter. These tools are designed to help students solidify their understanding and prepare them for both exams and real-world applications.

We hope this textbook will inspire students to pursue further studies in biological sciences and appreciate the intricate complexity and beauty of cells, the building blocks of life.

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Taxonomical Chart of our journey

1.1 Overview: From Atoms to Cell :

Life organization at its most basic level starts with the atom, which is the smallest unit of matter. Joining with other atoms, atoms form molecules, which are groups of two or more atoms held together by chemical bonds. Molecules, in general, that participate in biological processes are usually very complex and large in living organisms and include different essential biomolecules such as proteins, lipids, carbohydrates, and nucleic acids.

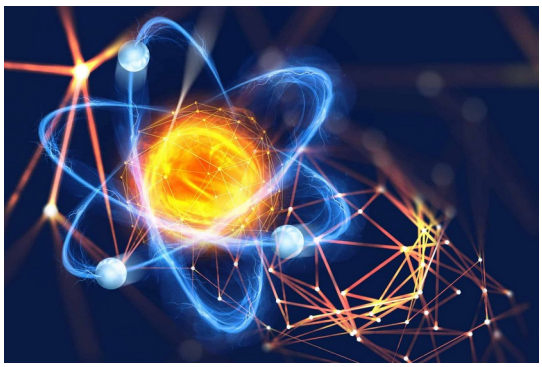


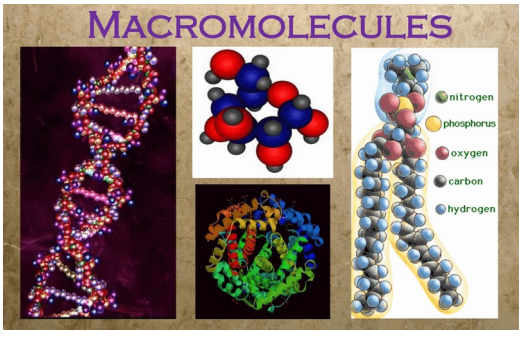
Figure 1 : Atom

1. Atoms to Molecules :

Atoms like carbon (C), hydrogen (H), oxygen (O), and nitrogen (N) are the most abundant atoms that form molecules of living cells. When these atoms combine, they form molecules. For example, two hydrogen atoms and one atom of oxygen combine to make up a molecule of water (H_2O), essential to living. Carbon atoms, however, form the backbone of most organic molecules.

2. Molecules to Macromolecules :

Molecules come together to make macromolecules. These are bigger, more complex molecules like proteins, nucleic acids (DNA and RNA), lipids or fats, and carbohydrates or sugars. All types of macromolecules perform a unique function in the cell:



Proteins function as enzymes, structural components, and molecules.

Nucleic acids store and transmit genetic information.

Lipids comprise the cell membrane and furnish energy.

Carbohydrates provide energy and structural support.

Figure 2 :

Macromolecules

3. Macromolecules to Organelles :

In the cell, macromolecules are put together to form structures called organelles which possess specific functions. Thus,

Nucleus: Has DNA - the genetic material that controls all activities of the cell

Mitochondria: Site of cellular respiration to provide energy to the cell

Endoplasmic Reticulum and Golgi Apparatus: Synthesis and transport of proteins

Lysosomes: Digest waste material and cellular debris

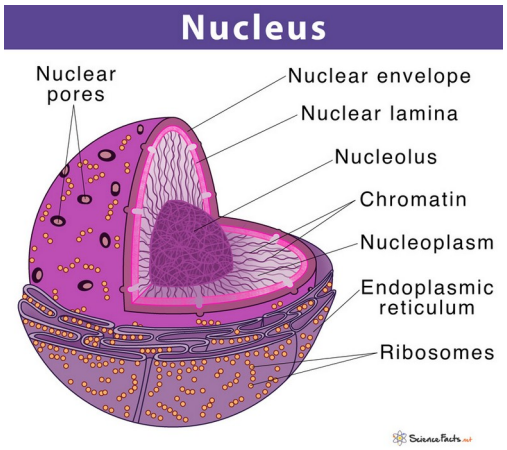


Figure 3 :

Nucleus

4. Organelles to Cells :

The final stage in this cycle is cell formation, the smallest unit of life. A cell is a very organized structure composed of various organelles working together in maintaining life processes. The cells are enclosed by a cell membrane, which regulates what enters and leaves the cell to help in the maintenance of the internal environment. There are mainly two major types of cells:

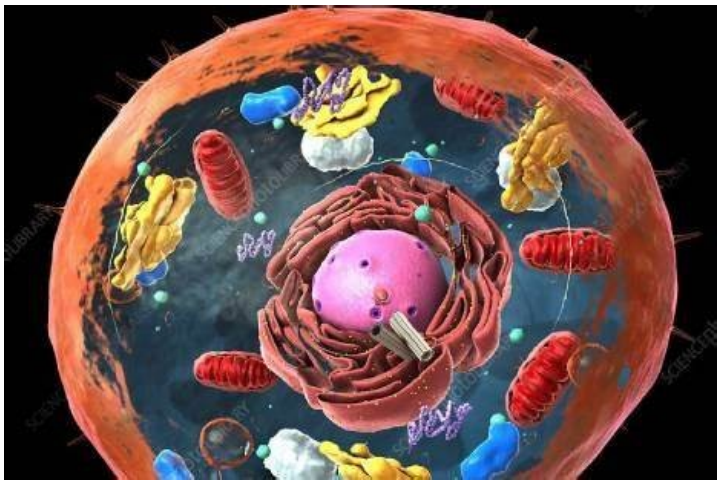


Figure 4 : cell

1.2 Animal Cell :

An animal cell is the basic structural and functional unit of life in animals. It is a eukaryotic cell, meaning it contains a true nucleus and various specialized membrane-

bound organelles. Animal cells vary in size and shape, depending on their function, but they typically have a flexible, round, or irregular shape due to the absence of a rigid cell wall (which plant cells have).

1. Plasma Membrane (Cell Membrane) :

Discovery:

Figure 4 : S.J. Singer and G.L. Nicolson

The cell membrane was firstly observed in 1855 by Carl Naegeli and C. Cramer. In 1972, S.J. Singer and G.L. Nicolson developed the "fluid mosaic model".

Structure:

The plasma membrane is a dynamic entity basically consisting of a phospholipid bilayer, with the hydrophilic (water-attracting) heads facing outwards and hydrophobic (water-repelling) tails facing inwards. This forms a semi-permeable barrier.

The membrane also embeds integral and peripheral proteins, cholesterol, and carbohydrate chains attached to proteins or lipids (glycoproteins and glycolipids). Integral proteins span the bilayer and have transport and signaling functions. Peripheral proteins are weakly attached to the surface of the membrane and participate in signaling and structural roles. Cholesterol maintains membrane fluidity impeding the membrane from becoming too rigid or too permeable. Function :

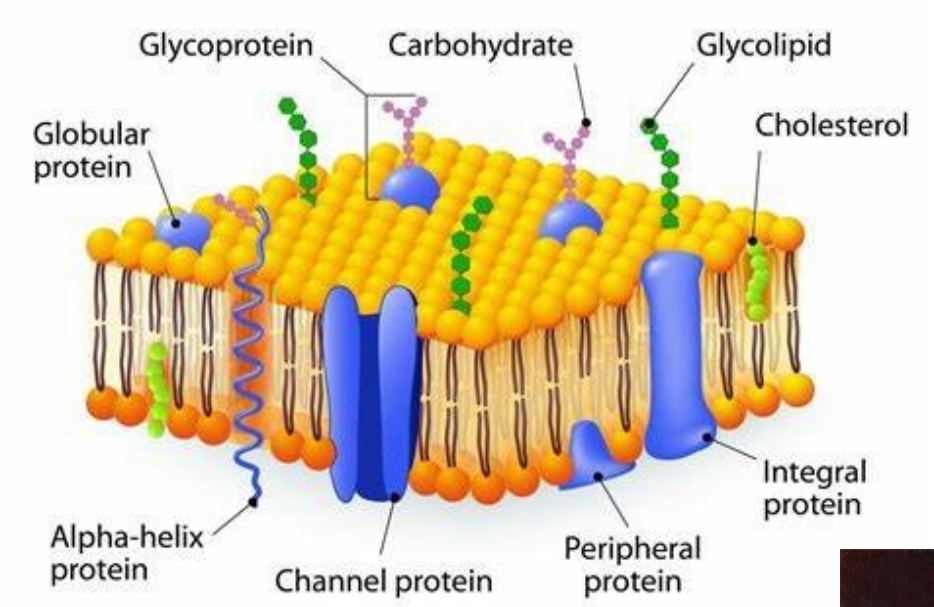


Figure 5 : Fluid Mosac Model by S.J. Singer and G.L. Nicolson

2. Nucleus :

Discovery :

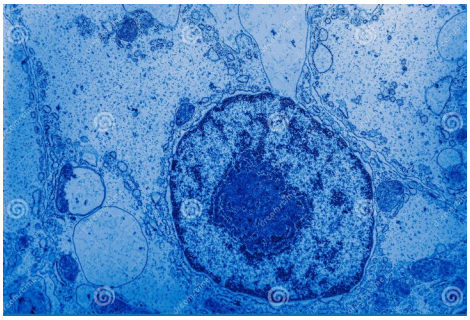
The nucleus was discovered by Robert Brown in 1831.

Structure:

The nuclear envelope consists of a double membrane with nuclear pores and surrounds the nucleus, mediating or regulating the passage of molecules such as RNA and proteins between the nucleus and the cytoplasm. Figure 6 : Robert Brown

Chromatin within the nucleus are loosely organized with DNA and proteins. However, at higher condensation in cell division, this forms chromosomes.

The nucleolus is a darkly staining portion of the nucleus associated with the synthesis of ribosomal RNA and assembly of ribosomal subunits.



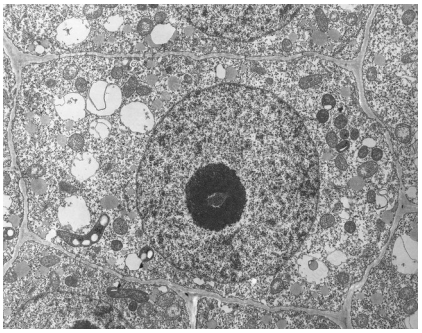
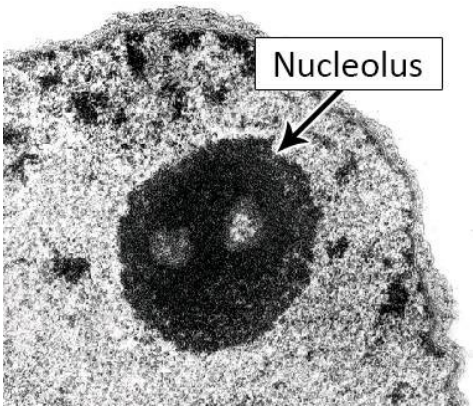


Figure 7 : shows the Nucleus under the Electron microscope

Function:

Genetic Control Center:

It is within the nucleus that most of the DNA in the cell is contained, with this DNA carrying genetic blueprints required by the cell to synthesize proteins and reproduce.



Transcription: Figure 8 : Nucleolus

Within the nucleus, the DNA is transcribed into messenger RNA, carrying the genetic message to the ribosomes.

Nucleolus Function:

It synthesizes r RNA, which then assembles along with proteins to form the ribosomes.

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3. Mitochondria :

Discovery:

First described as "bioblasts" by Richard Altmann in 1890 and later named mitochondria by Carl Benda in 1898.

Figure 9 : Richard Altmann Figure 10 : Carl Benda

Structure:

Organelles with double membrane:

Outer membrane: Smooth and permeable to small molecules.

Inner membrane:

Folded into cristae, which increase the surface area for ATP production.

Matrix:

Internal fluid containing mitochondrial

DNA, ribosomes, and enzymes responsible for different metabolic reactions.

Function:

Production of ATP: Mitochondria are cell "powerhouses" that produce energy via a process called oxidative phosphorylation; this is part of cellular respiration.

During this process, chemical energy from glucose and oxygen is transformed into the cell's main energy currency called adenosine triphosphate or ATP.

Apoptosis:

Mitochondria take part in programmed cell death, releasing cytochrome c to initiate cell destruction.

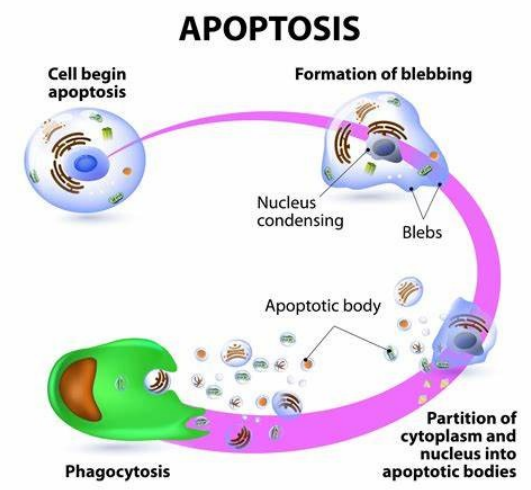


Figure 11 : Apoptosis

Metabolism:

Regulate fatty acid and amino acid metabolism.

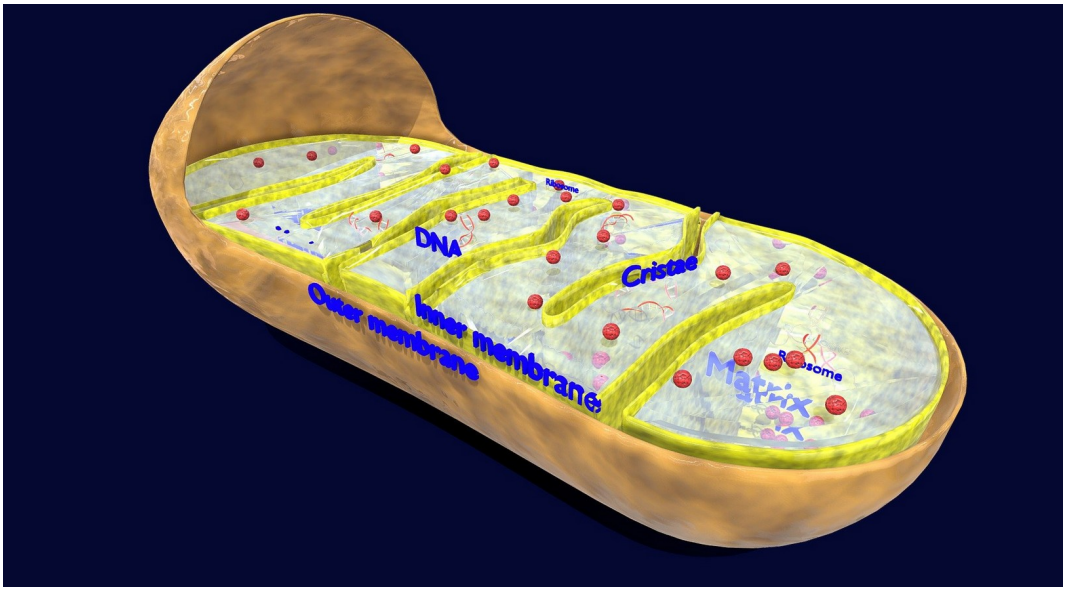


Figure 12 : shows the 3d structure of Mitochondria

4. Endoplasmic Reticulum (ER) :

Figure 13 : Keith Porter

Discovery:

By Keith Porter and colleagues in the year 1945.

Structure:

ER is an elaborated network of membranous tubules and sacs called cisternae. It exists in two forms:

Rough ER (RER): With ribosomes studded over its surface, it gives a rough look.

Smooth ER (SER): Without ribosomes, smooth in appearance.

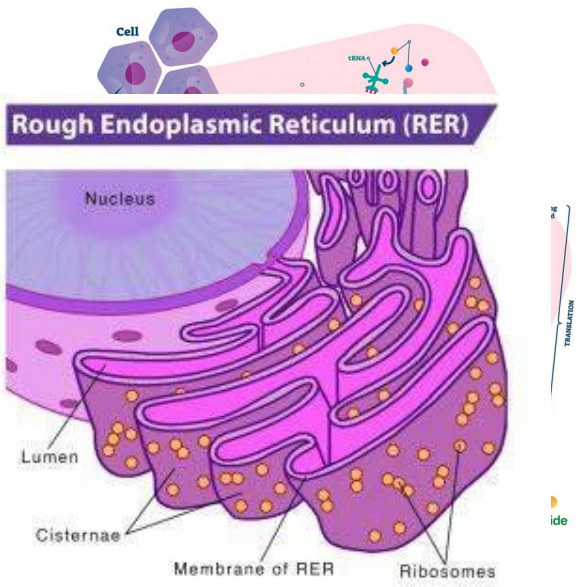
Function of Rough ER:

a] Protein Synthesis:

Proteins synthesized by the ribosomes on the rough ER are either secreted from the cell, inserted into the cell membrane, or sent to one of the organelles.

b] Protein Folding:

Proteins, after being synthesized, are folded into their functional shapes in the ER lumen. The



most common post-translational modification is the attachment of sugar molecules to proteins, called glycosylation, which often occurs as the protein passes through the ER and aids in the final function of the protein. Smooth ER functions include the following: Figure 14 Protein Synthesis

Figure 15 : Endoplasmic Reticulum

Figure 16 :Rough Endoplasmic Reticulum

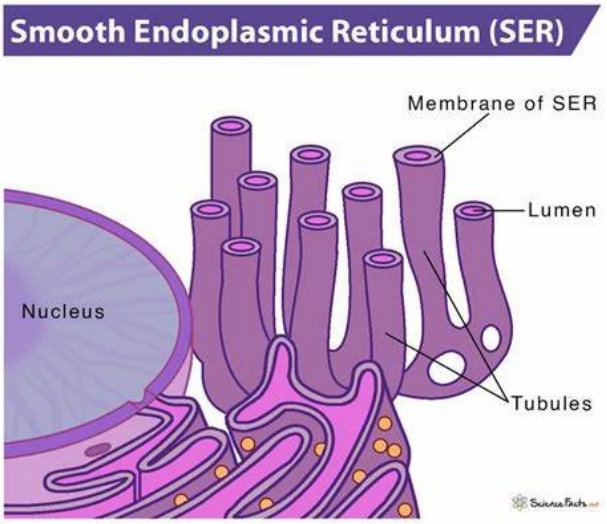
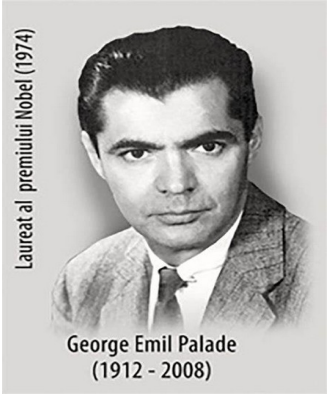


Figure 17 :Smooth Endoplasmic Reticulum

5. Ribosomes :



Discovery:

Discovered by George Palade in the 1950s by the use of electron microscopy.

Structure:

Ribosomes consist of two subunits-large and small-made up of ribosomal RNA and proteins. They are either:

1. Free Ribosomes: Figure 18 :George Palade

Floating freely in the cytoplasm, synthesizing proteins used within the cell.

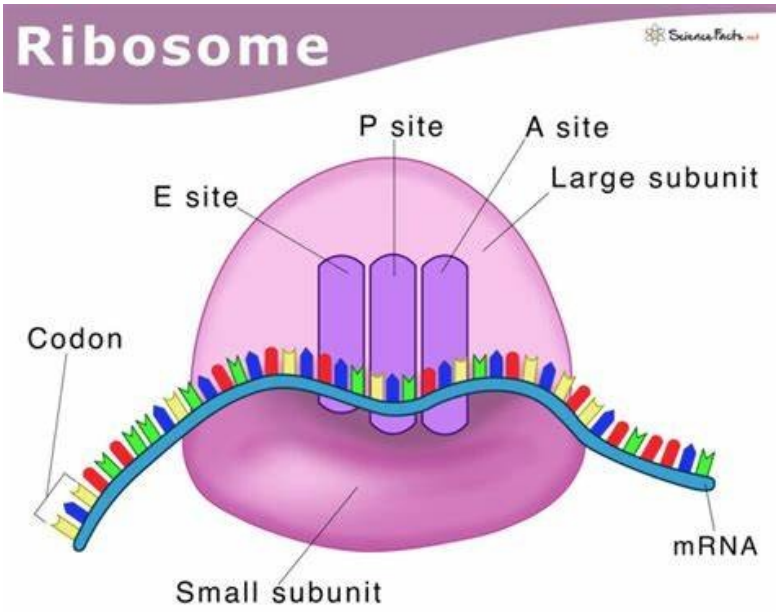
2. Bound Ribosomes:

Those that are bound to the rough ER and involved in protein synthesis, packaging, and transportation out of the cell, or into the various membranes.

Function:

Protein Synthesis: Translation of messenger RNA (mRNA) into polypeptide chains is done by ribosomes. They add the amino acids together in the correct order to construct proteins.

The large subunit joins the amino acids, while the small subunit reads the mRNA



sequence.

Figure 19 : Structure of Ribosomes

6. Golgi Apparatus (Golgi Body) :

Discovery:

Discovered in 1898 by Camillo Golgi, but only confirmed in the 1950s with the aid of electron microscopy.

Structure:

It is a flattened, disc-like organelle composed of a stack of membrane-bound sacs called cisternae. The Golgi has two distinct faces: the cis face, which is the side closest to the ER and where proteins and lipids jfirst enter it; and the trans face, the

side furthest from the ER where modified molecules are sorted and packaged in transport vesicles. Function:

Figure 20 : Camillo Golgi

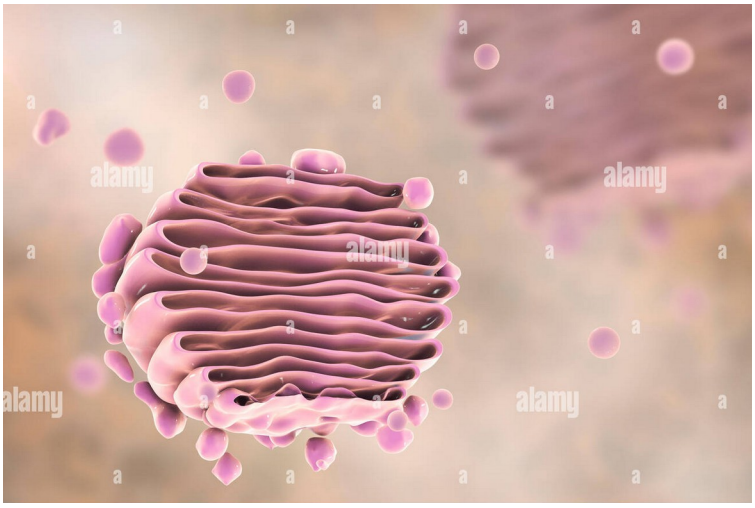
Modification of Proteins and Lipids:

Proteins and lipids arriving from the ER are further changed, for instance, by glycosylation or phosphorylation.

Packaging and Distribution:

After modification, the molecules are packaged into vesicles and transported to their destination site, for example, the plasma membrane, lysosomes, or secretion outside the cell.

Formation of Lysosomes: Lysosomes are formed in the Golgi apparatus.



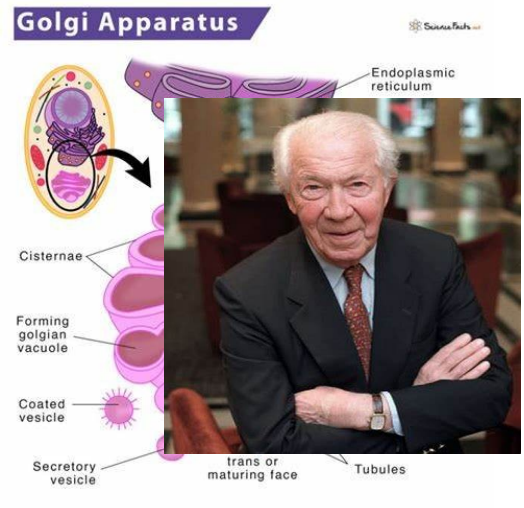


Figure 21 : 3D Structure of Golgi Bodies / Golgi Apparatus

7. Lysosomes :

Discovery:

The lysosomes were discovered by Christian de Duve in 1955

Figure 22 : Christian de Duve

Structure:

These are spherical organelles bound by a single membrane. They contain digestive enzymes, including proteases, lipases, nucleases, which

degrade macromolecules.

Function:

Intracellular Digestion: Lysosomes digest food particles, bacteria, and damaged organelles into simpler molecules that can be reused. Autophagy: It is associated with

the degradation and recycling of cellular components. Apoptosis: These release enzymes contributing to programmed cell death when necessary.

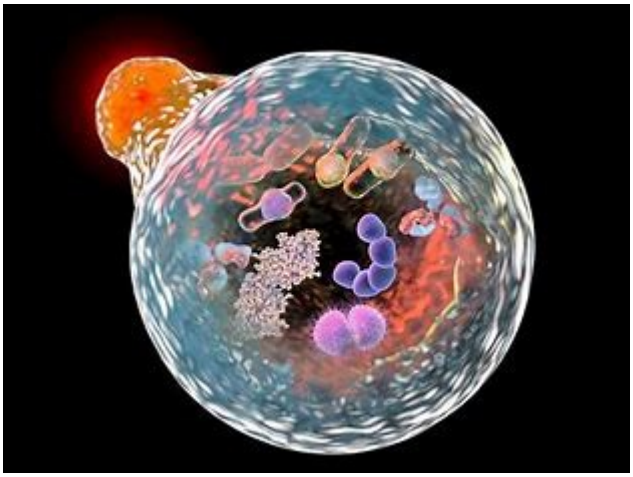


Figure 23 : 3d Structure of Lysosomes

Figure 24 : Lysosomes under the Microscope

8. Peroxisomes :

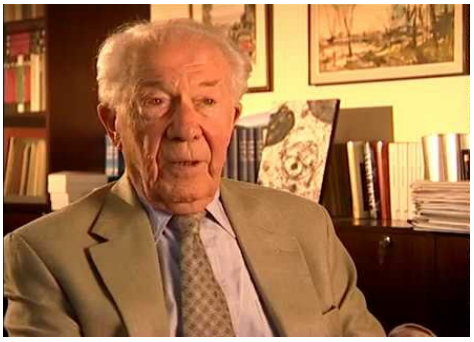


Figure 25 : Christian de Duve

Discovery:

Discovered by Christian de Duve in the year 1967.

Structure:

Small, membrane-bound organelles, housing enzymes including catalase and oxidases.

Function:

Fatty Acid Breakdown:

Peroxisomes participate in beta-oxidation, a process by which long-chain fatty acids are broken down into shorter molecules to supply energy.

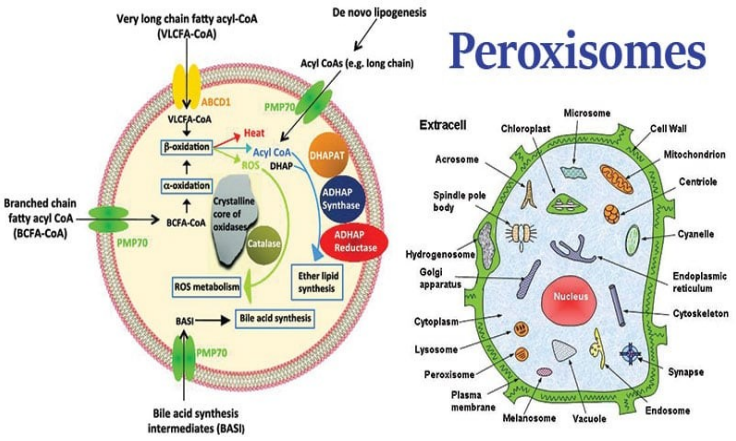


Figure 26 : Peroxisomes

Detoxification :

Detoxify harmful substances, such as hydrogen peroxide (H_2O_2), into water and oxygen using the enzyme catalase.

Lipid Biosynthesis:

Participate in the synthesis of some lipids, including plasmalogens, that are important in the brain and lungs.

9. Cytoplasm :

Discovery:

The term was given by Rudolf von Kölliker in 1862.

Structure:

A gel-like substance that is made up of water, salts, enzymes, and many organic molecules, including proteins, lipids, carbohydrates. Contains the cytoskeleton and organelles except for the nucleus.

Function:

Figure 27 : Rudolf von Kölliker

Site for Metabolic Activities: Many cellular activities, such as glycolysis, are carried out in the cytoplasm.

Support and Suspension: Gives a medium to organelles to stay suspended and allows their movement.

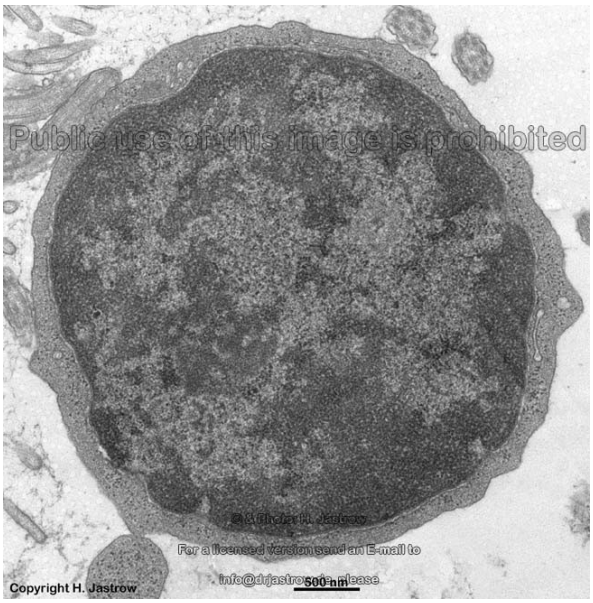

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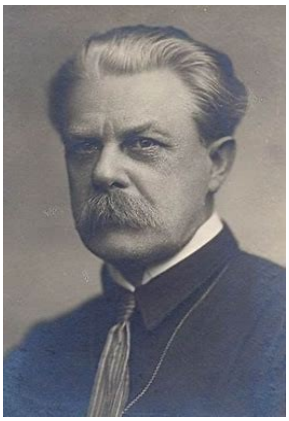
Figure 28 : Cytoplasm under the Microscope



10. Cytoskeleton :

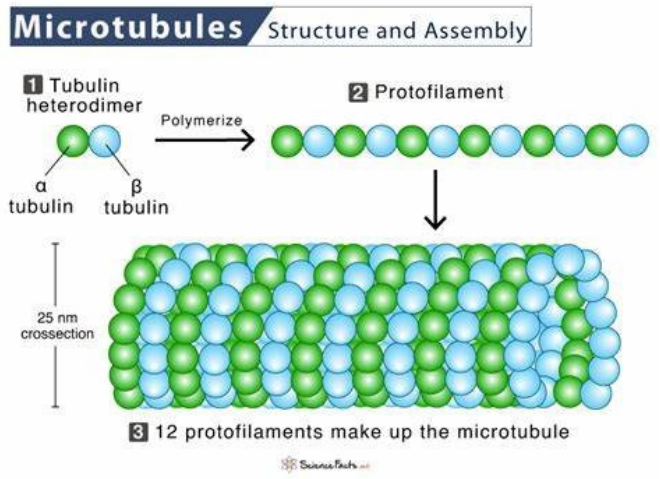
Discovery:

It was successively discovered, mainly by Nikolai Koltsov at the beginning of the 20th century.

Figure 29 : Nikolai Koltsov

Structure:

It is made up of three types of protein filaments in the cytoskeleton:



Microtubules: These are tubular entities made up of tubulin proteins, along with other accessory proteins. They help provide structural support for maintaining cell shape, in intracellular transport, and are importantly involved in the separation of chromosomes during cell division.

Microfilaments (Actin Filaments): The microfilaments contain thin strands of actin, which include other related proteins. They contribute to the locomotion of the cell, cytokinesis, and in muscle contraction.

Figure 30 Micro tubules

Intermediate Filaments: These are intermediate in diameter and help to provide mechanical strength and structural support.

Function:

Cell Shape and Structure:

The cytoskeleton maintains cell shape and allows cellular movement.

Intracellular Transport:

Provides a "highway" for the transport of organelles and vesicles.

Cell Division:

Provides the spindle apparatus that separates the chromosomes during mitosis.

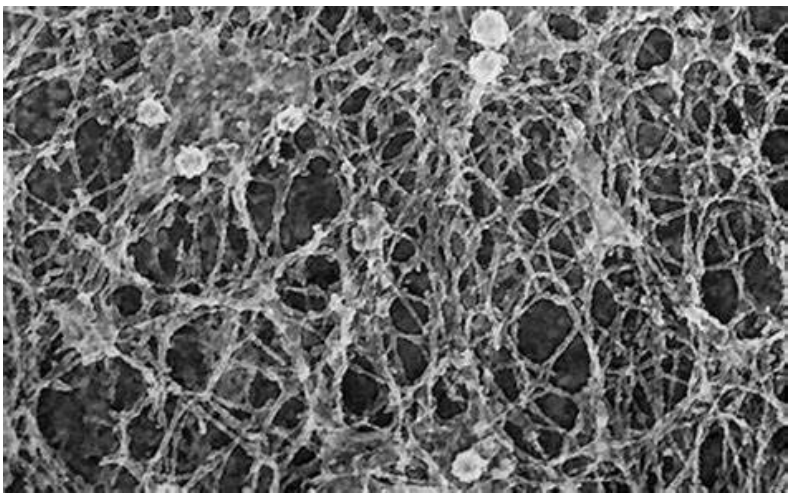


Figure 31 :cytoskeleton

11. Centrioles :

History:

Centrioles were first described by Edouard Van Beneden in 1883

Structure:

Centrioles are cylindrical structures composed of nine triplets of microtubules. They usually occur in pairs and are found near the nucleus in a region called the centrosome. Figure 32 : Edouard Van Beneden

Function:

Cell Division: Centrioles participate in the assembly of the mitotic spindle, responsible for separating chromosomes in the course of cell division, both mitosis and meiosis.

Cilia and Flagella Formation: Centrioles form the basal bodies from which cilia and flagella arise. These latter structures are involved in locomotion.

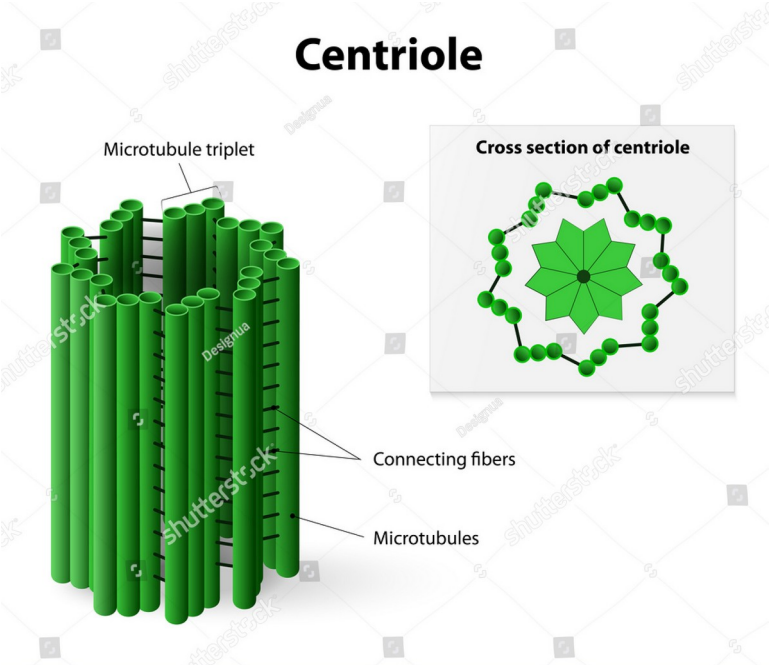


Figure 33 : Structure of Centriole

12. Vacuoles :

Discovery:

Discovered by Anton van Leeuwenhoek in the year 1676 in plant cells but also found in animal cells

Structure:
Figure 34 : Anton van Leeuwenhoek

Vacuoles are membranous sacs, though they are far smaller and less noticeable in animal cells than in plant cells.

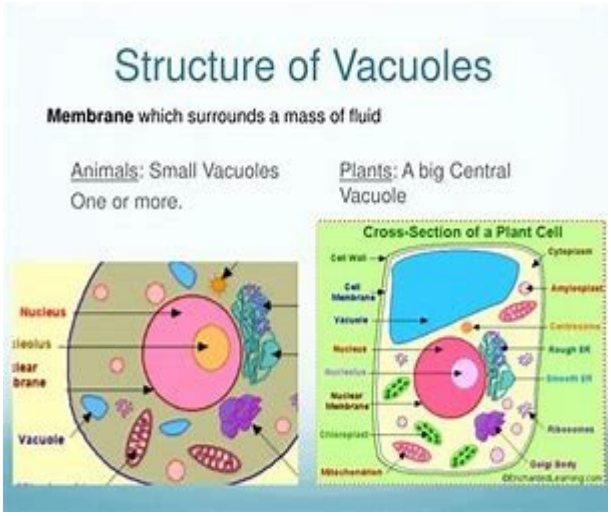


Figure 35 : Vacuole

Function:

Storage:

Nutrients, waste products, and ions are stored in these vacuoles.

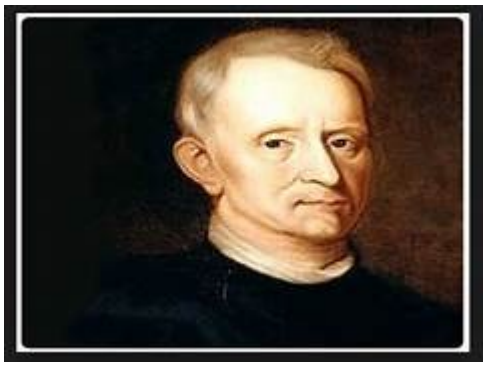
Waste Disposal:

Help get rid of useless substances from the cell.

Maintenance of Osmotic Balance:

Keeps the internal balance of water and ions in the cell.

1.2 Plant Cell :



Unique to plant Organelles that and not found in Animal cells:

1. Cell Wall :

Discovery:

It was first described by Robert Hooke in the year 1665 while he was examining cork under a microscope.

Figure 36 : Robert Hooke

Structure:

The cell wall is a rigid outer layer with cellulose as its major component, coupled with other polysaccharides such as hemicellulose and pectin.

It is located outside the plasma membrane and consists of two layers: the primary cell wall, which is flexible and found in growing cells, and the secondary cell wall, which is rigid and found in mature cells.

Function:

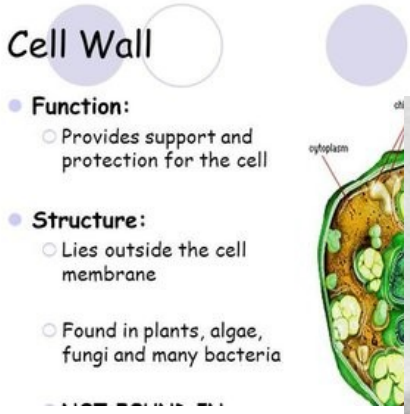
Structural Support: The cell wall provides shape to a plant cell and prevents over-expansion when water enters the cell.

Protection: It provides a protective barrier against mechanical stress and attacks by pathogens.

Turgor Pressure: Cooperating with the vacuole, it aids in maintaining the turgor pressure that keeps the plant cell rigid and thus can hold the plant upright.

Communication: The cell wall also consists of tiny channels known as plasmodesmata, which connect the adjacent plant cells for communication as well as transportation of materials from one cell to another.

Figure 37 : Cell Wall under the Microscope



Structure of Cell Wall

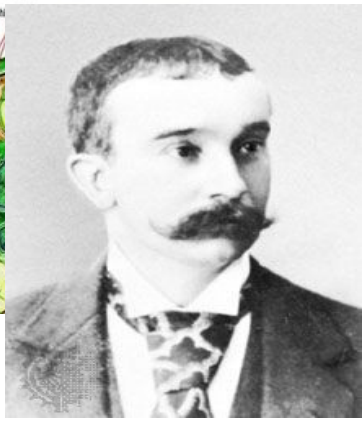


Figure 38

2. Chloroplasts :

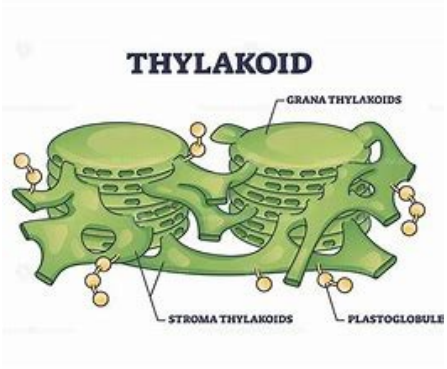
Discovery: Chloroplasts were described first by Andreas Schimper in the year 1883.

Structure:

Chloroplasts are double membrane-bound organelles.

Figure 39 : Andreas Schimper

Inside the chloroplast, the inner membrane encloses the stroma, a fluid that contains enzymes and chloroplast DNA. The stroma also contains stacks of thylakoids, which are disc-shaped sacs where chlorophyll resides and sunlight is absorbed. These thylakoids are organized into grana (singular: granum).



Function:

Photosynthesis: Chloroplasts are those organelles where photosynthesis occurs; it is the process in which light energy of the sun is converted by plants into chemical energy with the help of carbon dioxide and water, resulting in the production of glucose and oxygen. Photosynthesis is absolutely essential to the growth and metabolism of plants. Light

Absorption: Chlorophyll is the major pigment that absorbs sunlight for photosynthesis. It absorbs most of the light from the blue and red regions of the visible spectrum, hence allowing the green color of chlorophyll to reflect.

Figure 40 : Thylakoids

Synthesis of Organic Compounds: Chloroplasts manufacture fatty acids and amino acids by using them in the various anabolic processes of the plant.

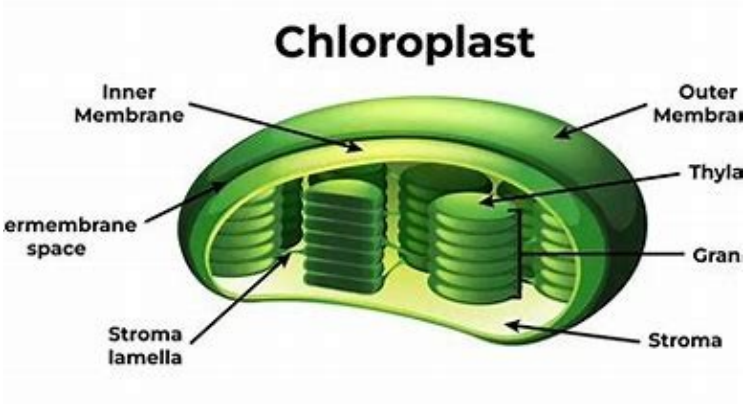


Figure 41 : Structure of Chloroplast

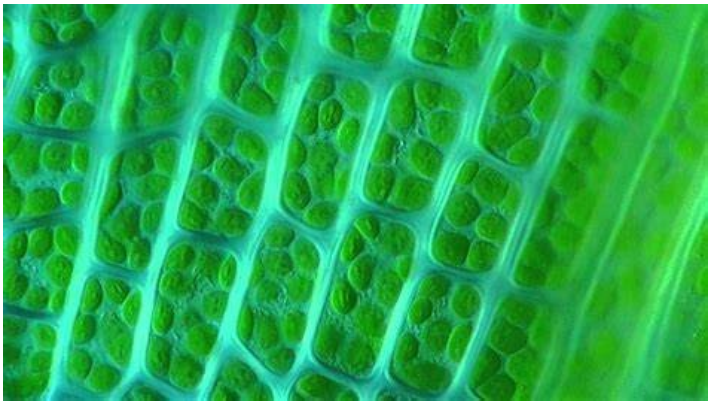


Figure 42 : Chloroplast under Microscope

3. Large Central Vacuole :

Discovery:

It was first described by Anton van Leeuwenhoek in 1676.

Figure 43 : Anton van Leeuwenhoek

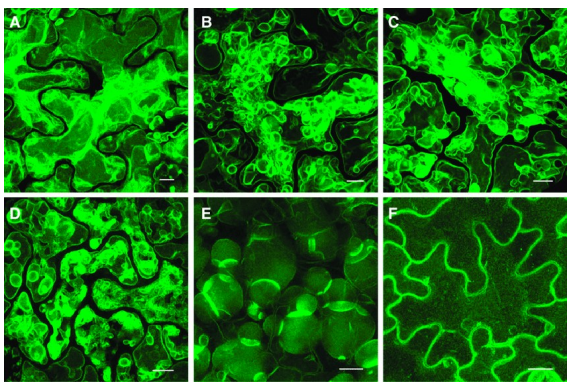
Structure:

The large central vacuole is a membrane-bound sac filled with cell sap, a solution of water, enzymes, ions, salts, and sometimes pigments.

It is enclosed by a special type of membrane called a tonoplast, which is selective in the regulation of passage of ions and molecules inside and outside the vacuole.

Function:

Storage: Nutrients-as for example, sugars and amino acids-waste products, and pigments-for example



anthocyanins, responsible for the coloration of flowers-are stored within the vacuole.

Figu

re 44 : Structure of Tonoplast

Maintenance of Turgor Pressure: Vacuoles serve in the maintenance of turgor pressure, where their inflation with water allows the cell membrane to stretch towards the cell wall, thus making the plant stand rigid and erect.

Waste Disposal: This is also a storage vacuole which contains waste products and poisonous materials. Thus it also acts as the site for detoxification.

Cell Growth: Due to this property, in growing plants, the vacuole is able to enlarge by taking up water, reducing the requirement for fresh cytoplasmic contents, and thus allowing the plant cell to become larger without significant rise in cytoplasm volume.

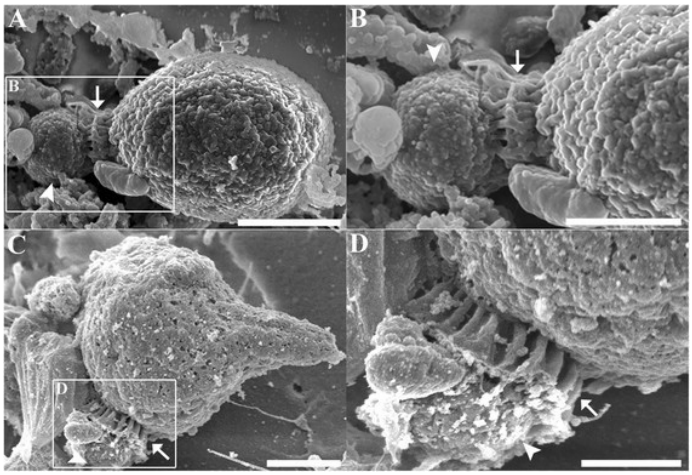


Figure 45 : Vacuole under Electron Microscope

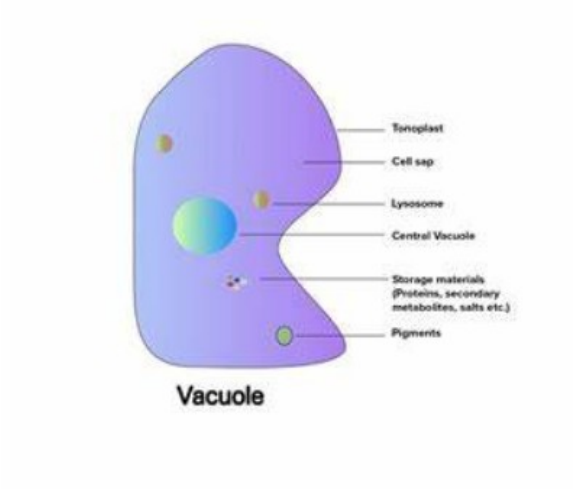


Figure 46 : Structure of Vacuole

4. Plasmodesmata :

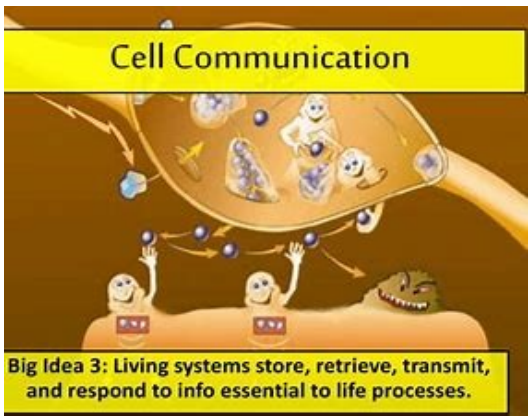
Discovery: First identified by Eduard Tangl in 1879.

Figure 47 : Eduard Tangl

Structure:

Plasmodesmata are tiny channels that perforate the cell walls of plant cells, connecting their cytoplasm.

These channels are lined by plasma membrane and are connected with thin strands of cytoplasm from adjacent cells, which enables transport.

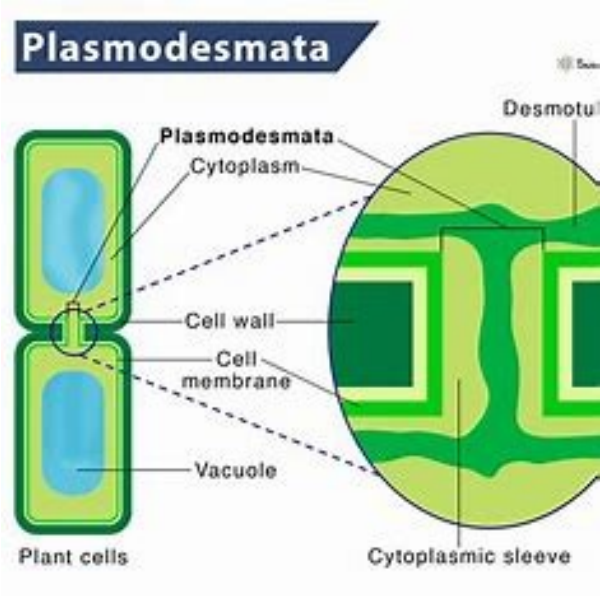


Functions :

Cell-Cell Communication: Plasmodesmata enable neighboring plant cells to communicate directly with each other through the transport of ions, nutrients, signaling molecules, and other substances from one cell to another.
F igure 48 : Cell Communication

Coordination: The plant cells use plasmodesmata for intercellular communication, thereby coordinating activities like growth and development, and environmental responses of plants.

Transport: Even large molecules including proteins and RNA could be transported through plasmodesmata to help in co-ordinating the activities of the cells in different parts of the plant.



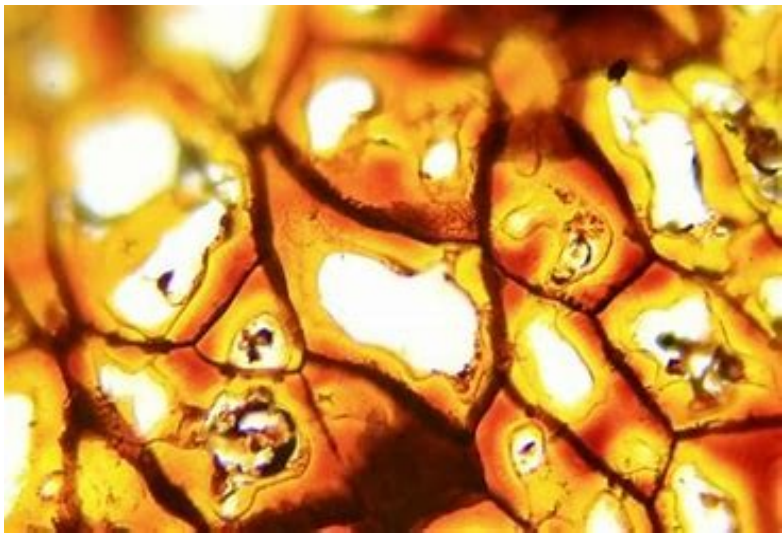


Figure 49 : Plasmodesmata

Figure 50 : Plasmodesmata under the microscope

Difference between Prokaryotic & Eukaryotic cell :

Feature	Animal Cells	Plant Cells
Cell Wall	Absent	Present; made of cellulose
Chloroplasts	Absent	Present; contains chlorophyll for photosynthesis
Large Central Vacuole	Small or absent	Large central vacuole; stores nutrients and maintains turgor pressure
Shape	Irregular or round	Typically rectangular or boxy due to cell wall
Centrioles	Present; involved in cell division	Absent; plant cells use other structures for cell division
Plasmodesmata	Absent	Present; channels connecting adjacent plant cells
Lysosomes	Present; involved in digestion and waste removal	Rarely present; functions often handled by vacuole
Storage	Glycogen (in liver and muscle cells)	Starch (energy storage)
	genetic exchange via conjugation	reproduction (mitosis)

Difference between Animal & Plant Cell :

Table of Animal Organelles along with their Discovery & Definition :

Organelle	Discovery	Definition
Nucleus	Discovered by **Robert Brown** (1831)	The central organelle that contains the cell's genetic material (DNA) and controls cellular activities.
Plasma Membrane	Observed by **Robert Hooke** (1665)	The outer membrane of the cell composed of a phospholipid bilayer with embedded proteins, controlling substance movement in and out of the cell.
Mitochondria	Described by **Richard Altmann** (1890)	Membrane-bound organelles known as the "powerhouses" of the cell, generating ATP through cellular respiration.
Endoplasmic Reticulum (ER)	Described by **Keith Porter** (1940s)	Network of membrane-bound tubules and sacs. Rough ER has ribosomes and synthesizes proteins, while Smooth ER is involved in lipid synthesis and detoxification.
Ribosomes	Discovered by **George Palade** (1950s)	Small, non-membrane-bound structures where protein synthesis occurs. Ribosomes can be free in the cytoplasm or attached to the rough ER.
Golgi Apparatus	Discovered by **Camillo Golgi** (1898)	A stack of flattened membranes that modifies, sorts, and packages proteins and lipids for transport to different locations inside or outside the cell.
Lysosomes	Discovered by **Christian de Duve** (1955)	Membrane-bound vesicles containing digestive enzymes that break down waste materials and cellular debris.
Centrioles	Discovered by **Edouard Van Beneden** (1883)	Cylindrical structures composed of microtubules, involved in cell division and formation of cilia and flagella.
Cytoskeleton	Various contributors (e.g., **Nikolai Koltsov**)	A network of protein filaments and tubules (microtubules, microfilaments, intermediate filaments) that provides structural support, shape, and movement to the cell.
Vesicles	Understanding evolved through 20th-century research	Small, membrane-bound sacs used for transporting materials within the cell and involved in processes such as exocytosis and endocytosis.

Table of Plant Organelles along with their Discovery & Definition :

Organelle	Discovery	Definition
Cell Wall	Observed by **Robert Hooke** (1665)	A rigid outer layer made primarily of cellulose that provides structural support and protection.
Chloroplasts	Described by **Andreas Schimper** (1883)	Membrane-bound organelles containing chlorophyll, where photosynthesis occurs, converting light energy into chemical energy.
Large Central Vacuole	Observed by **Anton van Leeuwenhoek** (1676)	A large, membrane-bound sac filled with cell sap that stores nutrients, waste products, and helps maintain turgor pressure.
Plasmodesmata	Observed by **Eduard Tangl** (1879)	Microscopic channels that pass through the cell walls of plant cells, allowing for direct exchange of materials and communication between adjacent cells.
Peroxisomes	Described by **Christian de Duve** (1967)	Membrane-bound organelles containing enzymes like catalase and oxidases that are involved in detoxifying harmful substances and breaking down fatty acids.

Types of Cell :

Type	Description	Examples
Prokaryotic Cells	Simple, unicellular organisms without a nucleus or membrane-bound organelles.	Bacteria, Archaea
Eukaryotic Cells	Complex cells with a nucleus and membrane-bound organelles.	Animal cells, Plant cells, Fungi
Stem Cells	Undifferentiated cells that can differentiate into various specialized cell types.	Embryonic stem cells, Adult stem cells
Somatic Cells	Any cell in a multicellular organism except germ cells (reproductive cells).	Skin cells, Muscle cells, Nerve cells
Germ Cells	Cells involved in reproduction, capable of giving rise to gametes (sperm and egg cells).	Sperm cells, Egg cells

Cell Cycle Phases :

Phase	Description
Interphase	The phase where the cell grows and DNA is replicated. Includes G1, S, and G2 phases.
G1 Phase (Gap 1)	Cell grows and synthesizes proteins necessary for cell division.
S Phase (Synthesis)	DNA replication occurs, resulting in two sets of chromosomes.
G2 Phase (Gap 2)	Cell prepares for mitosis by synthesizing organelles and other molecules needed for cell division.
M Phase (Mitosis)	Cell divides into two identical daughter cells. Consists of Prophase, Metaphase, Anaphase, and Telophase.
Cytokinesis	Cytoplasmic division resulting in two daughter cells, each with its own nucleus.

Phases of Mitosis :

Phase	Description
Prophase	Chromatin condenses into chromosomes, nuclear membrane dissolves, spindle fibers form.
Metaphase	Chromosomes line up at the cell's equatorial plate, and spindle fibers attach to the centromeres.
Anaphase	Sister chromatids separate and move toward opposite poles of the cell.
Telophase	Chromosomes decondense, nuclear membranes reform, and the spindle fibers break down.
Cytokinesis	Cytoplasm divides, resulting in two daughter cells with identical genetic information.

Difference Between Meiosis & Mitosis :

Feature	Mitosis	Meiosis
Purpose	Growth, repair, and asexual reproduction	Sexual reproduction (producing gametes)
Number of Divisions	One division (two identical daughter cells)	Two divisions (four non-identical daughter cells)
Number of Daughter Cells	Two diploid (2n) cells	Four haploid (n) cells
Genetic Variation	No variation; daughter cells are genetically identical	Genetic variation due to crossing over and independent assortment
Occurs In	Somatic cells	Germ cells

Modes of Transport Across Cell Membranes :

Type of Transport	Description	Energy Required?
Diffusion	Movement of molecules from an area of high concentration to low concentration (passive process).	No
Facilitated Diffusion	Movement of molecules across the membrane via protein channels from high to low concentration.	No
Osmosis	Movement of water molecules across a selectively permeable membrane from a region of low solute concentration to high solute concentration.	No
Active Transport	Movement of molecules from low concentration to high concentration using energy (ATP).	Yes
Endocytosis	Process by which cells engulf material into vesicles.	Yes
Exocytosis	Process by which cells expel material from vesicles.	Yes

Major Cell Organelles and Their Discoverers :

Organelle	Discovery	Discoverer
Nucleus	1831	Robert Brown
Mitochondria	1890	Richard Altmann
Endoplasmic Reticulum	1945	Keith Porter
Golgi Apparatus	1898	Camillo Golgi
Ribosomes	1955	George Palade
Lysosomes	1955	Christian de Duve
Chloroplasts	1883	Andreas Schimper
Cell Membrane	Mid-1600s (basic understanding)	Robert Hooke

Types of Cellular Junctions :

Junction Type	Description	Location
Tight Junctions	Seals neighboring cells together in an epithelial sheet to prevent leakage of molecules between them.	Epithelial tissues (e.g., intestines)
Desmosomes	Anchoring junctions that hold adjacent cells together; strong connections.	Skin and cardiac muscle cells
Gap Junctions	Channels that allow ions and small molecules to pass between adjacent cells for communication.	Cardiac cells, smooth muscle cells
Plasmodesmata	Channels in plant cell walls that allow communication and transport between adjacent plant cells.	Plant cells

Differences Between Autotrophic and Heterotrophic Cells :

Characteristic	Autotrophic Cells	Heterotrophic Cells
Energy Source	Produce their own food through photosynthesis or chemosynthesis	Obtain energy by consuming organic compounds
Organelles	Contain chloroplasts for photosynthesis	Lack chloroplasts; rely on mitochondria for energy
Examples	Plant cells, algae	Animal cells, fungi, some bacteria
Type of Nutrition	Autotrophic (self-feeding)	Heterotrophic (other-feeding)
Process	Convert light energy into chemical energy (glucose)	Break down food molecules for energy (cellular respiration)
Storage of Energy	Store energy as starch	Store energy as glycogen or fat

Stages of Meiosis :

Phase	Description
Prophase I	Chromosomes condense, homologous chromosomes pair up, crossing-over occurs, spindle fibers form.
Metaphase I	Homologous chromosome pairs align at the cell equator.
Anaphase I	Homologous chromosomes separate and move to opposite poles of the cell.
Telophase I	Chromosomes reach opposite poles, nuclear membranes reform, and the cell divides (cytokinesis).
Prophase II	Spindle fibers form in each daughter cell, chromosomes condense.
Metaphase II	Chromosomes align at the equator in each daughter cell.
Anaphase II	Sister chromatids separate and move to opposite poles in each daughter cell.
Telophase II	Chromatids reach the poles, nuclear membranes reform, and cytokinesis results in four haploid cells.

Differences Between Active and Passive Transport :

Feature	Active Transport	Passive Transport
Energy Requirement	Requires energy (ATP)	No energy required
Direction of Movement	Against concentration gradient (low to high)	Down concentration gradient (high to low)
Examples	Sodium-potassium pump, endocytosis, exocytosis	Diffusion, osmosis, facilitated diffusion
Membrane Proteins	Requires transport proteins or pumps	Can occur with or without transport proteins
Types of Molecules	Large molecules, ions	Small nonpolar molecules, gases (O_2, CO_2)

Types of Microscopy :

Type of Microscopy	Description	Resolution	Used For
Light Microscopy	Uses visible light to magnify objects. Commonly used in classrooms and basic biological studies.	Up to 200 nanometers (nm)	Studying live cells, tissues
Electron Microscopy (EM)	Uses beams of electrons for greater resolution. Includes TEM (Transmission) and SEM (Scanning) microscopy.	Up to 0.1 nanometers (TEM), 1 nm (SEM)	Viewing ultrastructure of cells
Fluorescence Microscopy	Uses fluorescent stains and dyes to visualize specific cellular structures and proteins.	~200 nanometers	Studying specific proteins and organelles
Confocal Microscopy	Uses laser light and optical sectioning to create a 3D image of cells or tissues.	~200 nanometers	High-resolution 3D imaging

ATP Production in Cellular Respiration :

Stage	Location	ATP Yield	Description
Glycolysis	Cytoplasm	2 ATP	Glucose is broken down into pyruvate, yielding ATP and NADH.
Krebs Cycle (Citric Acid Cycle)	Mitochondrial matrix	2 ATP	Acetyl-CoA is broken down, producing ATP, NADH, and $FADH_2$.
Electron Transport Chain	Inner mitochondrial membrane	32-34 ATP	Electrons from NADH and $FADH_2$ are transferred through protein complexes, driving ATP synthesis.
Total ATP Yield	Entire process	36-38 ATP	Complete breakdown of one glucose molecule generates approximately 36-38 ATP molecules.

Differences Between Photosynthesis and Cellular Respiration :

Feature	Photosynthesis	Cellular Respiration
Organisms	Plants, algae, some bacteria	All living organisms
Energy Source	Sunlight (converts light energy into chemical energy)	Chemical energy (from glucose and other molecules)
Reactants	Carbon dioxide, water, and sunlight	Glucose and oxygen
Products	Glucose and oxygen	Carbon dioxide, water, and ATP
Location	Chloroplasts (in plants)	Mitochondria (in eukaryotes), cytoplasm (in prokaryotes)
Purpose	Store energy in the form of glucose	Release energy stored in glucose for

Cellular Respiration: Aerobic vs. Anaerobic Respiration :

Feature	Aerobic Respiration	Anaerobic Respiration
Oxygen Requirement	Requires oxygen	Occurs without oxygen
Location	Mitochondria (in eukaryotes)	Cytoplasm
End Products	Carbon dioxide, water, ATP	Lactic acid (in animals), ethanol (in yeast)
ATP Yield	36-38 ATP per glucose molecule	2 ATP per glucose molecule
Organisms	Most eukaryotes (plants, animals, fungi)	Yeasts, bacteria, muscle cells (during low oxygen)
Efficiency	High (due to complete oxidation of glucose)	Low (incomplete oxidation of glucose)

Components of the Plasma Membrane :

Component	Description	Function
Phospholipids	A bilayer of phospholipids, with hydrophobic tails and hydrophilic heads.	Forms the basic structure of the membrane; provides barrier.
Proteins	Integral and peripheral proteins embedded in or attached to the membrane.	Transport, signaling, structural support, enzyme activity.
Cholesterol	A lipid found between phospholipids in the membrane (in animal cells).	Regulates membrane fluidity and stability.
Carbohydrates	Short chains of sugars attached to proteins (glycoproteins) or lipids (glycolipids).	Involved in cell recognition and signaling.
Transport Proteins	Channels or carriers that help in the transport of specific molecules across the membrane.	Facilitate passive and active transport.
Receptor Proteins	Proteins that bind signaling molecules (ligands) and initiate a cellular response.	Involved in cell communication and signal transduction.

Protein Synthesis: Transcription vs. Translation :

Feature	Transcription	Translation
Location	Nucleus (eukaryotes), cytoplasm (prokaryotes)	Cytoplasm (on ribosomes)
Purpose	Synthesis of mRNA from DNA template	Synthesis of protein from mRNA template
Molecule Produced	mRNA (messenger RNA)	Polypeptide chain (protein)
Main Enzymes Involved	RNA polymerase	Ribosomes, tRNA, and aminoacyl-tRNA synthetase
Major Steps	Initiation, Elongation, Termination	Initiation, Elongation, Termination
Template Used	DNA	mRNA

Types of Cellular Communication :

Type	Description	Example
Autocrine	A cell targets itself by releasing signaling molecules that bind to receptors on its own surface.	Immune cells secreting cytokines
Paracrine	A cell targets a nearby cell, with signals diffusing over a short distance.	Neurons releasing neurotransmitters
Endocrine	A cell targets a distant cell by releasing hormones into the bloodstream.	Insulin secretion by pancreas
Juxtacrine	Cells directly communicate through contact-dependent signaling, often involving membrane-bound proteins.	Cells of the immune system interacting directly
Synaptic	A specialized form of paracrine signaling where nerve cells communicate through synapses.	Neuron-to-neuron communication

Cellular Organelles and Their Associated Diseases :

Organelle	Associated Disease	Description of Disease
Mitochondria	Mitochondrial Myopathies	Disorders due to dysfunctional mitochondria, affecting energy production.
Lysosomes	Lysosomal Storage Disorders (e.g., Tay-Sachs Disease)	Accumulation of substances in lysosomes due to enzyme deficiency.
Nucleus	Progeria	A genetic disorder caused by mutations in nuclear lamina proteins, leading to premature aging.
Peroxisomes	Zellweger Syndrome	A disorder

Cellular Organelles and Their Associated Diseases :

Organelle	Associated Disease	Description of Disease

Phase	Description	Key Events
G_1 Phase	The cell grows and synthesizes proteins necessary for DNA replication.	Growth, preparation for DNA synthesis
S Phase	DNA replication occurs, resulting in the duplication of chromosomes.	DNA is synthesized (each chromosome now has two sister chromatids)
G_2 Phase	The cell continues to grow and prepares for mitosis, producing proteins and organelles.	Final preparation for cell division
M Phase (Mitosis)	The cell divides its duplicated chromosomes into two daughter nuclei.	Prophase, Metaphase, Anaphase, Telophase (mitosis stages)
Cytokinesis	The cytoplasm divides, producing two genetically identical daughter cells.	Cytoplasm division, separation of daughter cells
G_0 Phase	A resting phase where the cell has left the cycle and is not actively dividing.	Cell exits cycle (can be temporary or permanent)

Phases of the Cell Cycle :

Types of Membrane Transport :

Type of Transport	Description	Example
Simple Diffusion	Movement of small, nonpolar molecules across the membrane down their concentration gradient.	Oxygen (O_2), carbon dioxide (CO_2)
Facilitated Diffusion	Movement of molecules across the membrane via specific transport proteins, down the concentration gradient.	Glucose transport via GLUT1, ion channels
Active Transport	Movement of molecules against their concentration gradient, requiring energy (ATP).	Sodium-potassium pump (Na^+/K^+ pump)
Endocytosis	Process by which cells engulf materials from outside by enclosing them in a vesicle.	Phagocytosis of bacteria by white blood cells
Exocytosis	Process by which cells release materials outside by fusing vesicles with the plasma membrane.	Secretion of hormones like insulin
Osmosis	Diffusion of water across a semipermeable membrane, moving from an area of low solute concentration to high solute concentration.	Water absorption in plant roots

Major Types of Stem Cells :

Type of Stem Cell	Description	Potential
Totipotent	Can differentiate into any cell type, including extra-embryonic tissues (placenta).	Can form a complete organism (e.g., zygote)
Pluripotent	Can differentiate into almost any cell type but cannot form an entire organism.	Can form all three germ layers (e.g., embryonic stem cells)
Multipotent	Can differentiate into a limited range of cell types within a specific tissue or organ.	Can form related cell types (e.g., hematopoietic stem cells)
Unipotent	Can differentiate into only one specific cell type.	Limited to forming only one cell type (e.g., skin stem cells)

Cell Death: Apoptosis vs. Necrosis :

Feature	Apoptosis	Necrosis
Type of Process	Programmed cell death	Uncontrolled cell death
Cause	Natural, regulated process for removing damaged cells	Caused by injury, infection, or toxins
Outcome	Cell shrinks and fragments into apoptotic bodies	Cell swells and bursts, leading to inflammation
Inflammation	No inflammation (apoptotic bodies are phagocytosed)	Causes inflammation due to cell contents spilling into the tissue
Examples	Developmental processes, immune system regulation	Injury, ischemia (reduced blood flow)

Functions of the Cytoskeleton :

Component	Description	Function
Microfilaments (Actin Filaments)	Thin filaments composed of actin proteins.	Involved in cell movement, shape, and division
Intermediate Filaments	Rope-like fibers made of various proteins.	Provide structural support and mechanical strength
Microtubules	Hollow tubes made of tubulin proteins.	Involved in intracellular transport, cell division (mitotic spindle), and cilia/flagella movement

Common Cellular Staining Techniques :

Stain	Description	Used For
Hematoxylin and Eosin (H&E)	Hematoxylin stains cell nuclei blue, and eosin stains cytoplasm and extracellular matrix pink.	General tissue staining (histology)
Gram Stain	A differential stain used to classify bacteria as Gram-positive (purple) or Gram-negative (pink).	Identifying bacterial types
Wright-Giemsa Stain	A stain used to differentiate blood cells, with nuclei staining purple and cytoplasm pink.	Blood smear analysis
DAPI (4',6-diamidino-2-phenylindole)	A fluorescent stain that binds to DNA, emitting blue fluorescence under UV light.	Staining